# TMO TECHNOLOGY DEVELOPMENT PLAN

## Low Noise Systems Work Area

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**OBJECTIVE:**
Ka-band low-noise amplifier (LNA) technology will be developed and demonstrated to reduce the implementation and operating costs, and increase the reliability, sensitivity and RFI tolerance of ground-based cryogenic, low-noise amplifier systems.

**GOALS and SIGNIFICANCE:**
The goal is to develop and demonstrate stable and RFI insensitive Ka-band HEMT-based cryogenic low noise amplifier modules with noise temperatures of 11.0K or less and to complete the design study for a low cost ultra-low noise Ka-band maser with a 4K noise temperature. HEMT LNA systems are less expensive to implement and maintain, and more reliable than maser systems. Compared to masers, HEMTs cost $500K less per system to implement and $30K less per year per system to maintain and operate. However, a low cost ultra-low noise maser system could improve the G/T of DSN beam waveguide antennas by as much as 1.4 dB compared to that which will be achieved with future Ka-Band HEMT-based systems.

**PRODUCTS:**
The principal products of this work area are Ka-band cryogenic LNA modules for the DSN. In addition, the process of rapidly and reproducibly developing state-of-the-art LNAs required the development of a number of critical products or tools that are continuously being improved. These critical products include thousands of InP HEMT devices optimized for cryogenic operation, the first cryogenic wafer probe stations to characterize these devices, HEMT device small signal and noise models to design and develop HEMT LNA modules, and a low cost ultra-low noise maser design.

**DESCRIPTION:**
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**DELIVERABLES:**
- 2 each - 11 K, Ka-Band LNA modules for DSS13
- Completion of on-wafer characterization of 4th InP wafer run
- 2 each - 10 K, Ka-Band LNA modules for DSS25
- Completion of 5th and 6th InP wafer run
- Demonstration of on-wafer cryogenic noise parameter measurement at GIT
- Demonstration of 11 K, Ka MMIC/Hybrid LNA module
- Complete 32 GHz low cost maser ULNA design

**RESOURCE REQUIREMENTS BY WORK UNIT:**

| | JPL Account # | FY98 | FY99 | FY00 | FY01 | FY02 | FY03 |
|---|---|---|---|---|---|---|---|
| ***HEMT LNA Dev*** | 412-41102 | 560 | 545 | 545 | 535 | 545 | 520 |
| ***Total*** | | 560 | 776 | 766 | 776 | 805 | 805 |
| ***Total Workforce*** | | 2.1 | 2 | 2 | 2 | 2 | 1.8 |
| | | | | | | | |

# TMO TECHNOLOGY TASK DESCRIPTION

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| **TITLE:** **HEMT LNA Development** |
| **WORK UNIT IN WHICH FUNDED:** **HEMT LNA Development, 412-41102-0-333** |
| **WORK AREA:** **Low Noise Systems** |

**BRIEF TECHNICAL SUMMARY:**

Low-noise amplifier (LNA) technology will be developed and demonstrated that will lead to ground-based improvements in the spacecraft-to-earth telecommunications link. The improvements sought are lower front-end noise temperatures, reduced implementation and operating costs, and increased reliability and maintainability of receiving equipment.

The primary objective of this work area is to develop High Electron Mobility Transistor (HEMT)-based LNAs that meet or exceed the noise temperature performance of maser-based Closed Cycle Refrigerator (CCR) cooled LNAs. R&D HEMT devices will be evaluated and cryogenic HEMT-based low noise amplifiers (LNAs) at Ka-band will be developed. This will lead to the demonstration and implementation of HEMT-based LNA/CCR front-end systems comparable in performance to the best maser-based systems for a fraction of the cost.

The secondary object is to complete a low cost ultra-low noise maser system design. The basic maser design will be based on the successful dual cavity KABLE maser and will include an examination of trade-offs between an open cycle system and closed cycle system.

HEMT/CCR LNA versus maser/CCR LNA cost and RF performance will be monitored and documented. The comparisons in cost performance will include initial cost, MTBF, MTTR, and operating/personnel costs while the comparison in RF performance will include noise temperature, gain, stability and bandwidth. The improvements in HEMT-device performance, that is, lower noise and higher gain and wider bandwidth, have resulted in decreased device stability. Thus, for HEMT LNA performance improvements, innovations will include improving the HEMT LNA design to accommodate less stable, but higher performing, HEMT devices. To accomplish this the correlation between on-wafer measurements and computer models will be improved. Since the HEMTs are inherently broadband devices, the HEMT-based LNAs will be characterized to determine their susceptibility and response to various forms of RFI to specify the filtering requirements.

**JUSTIFICATION AND BENEFITS:**

HEMT-based LNAs are projected to meet or exceed the noise temperature performance of current maser-based LNAs by the end of 1998, and are less expensive to construct, more reliable, and more economical to operate and maintain than the maser-based LNAs. Furthermore, HEMT-based LNAs use 12K refrigerators which are less expensive to operate and are more reliable and easier to maintain than the 4.5K refrigerators required for maser-based LNAs. By implementing HEMTs instead of masers the DSN can save more than $500K per system on initial construction costs and $30K per system per year on maintenance and operation costs. However, super cooled masers will provide the best noise performance. Thus, HEMT LNAs are more likely than masers to meet the future requirements for the lowest maintenance cost and large bandwidths (for example, interferometric techniques for navigation, while low cost super cooled masers will provide the best sensitivity for the most exacting down-link situations.

The presence of in- and out-of-band RFI can result in an effective system noise temperature increase and gain compression in DSN receivers. The implementation of broad-band HEMT based LNAs, the increased use of multiple-band diplexing schemes, and new sources of RFI require experimental investigation to define the susceptibility of this new technology to present and anticipated future RFI. Successful implementation of ultra-low loss filtering strategies will protect the DSN from loss of valuable scientific data and enable implementation of low-noise diplexed feeds for the DSN.

**APPROACH AND PLAN:**

The HEMT program is based on a partnership among TRW, the Georgia Institute of Technology (GIT), and JPL. TRW will be responsible for iteratively improving device performance by varying the device materials. GIT will be responsible for evaluating the noise parameters of discrete HEMT and

MMIC devices at cryogenic temperatures and performing the modelling. JPL will evaluate the scattering parameters of the HEMT devices, design, construct and characterize the HEMT-based LNAs. Within JPL, there is additional teaming between the DSN (Div33) and SESPD (Div86) to meet TMOD's DSN LNA needs and SESPD's need for proposed earth orbiting radiometers.

At room temperature indium phosphide (InP) HEMTs are the lowest noise transistors available for frequencies above 1 GHz. TRW will conduct a variety of device studies to further improve device performance by increasing electron confinement and reducing electron scattering in InP HEMTs. These studies include variation of indium concentration, dopant concentrations and profiles, spacer layer thicknesses, and device geometry (shorter length gates and/or multiple gates, sources, and drains).

In order for TRW to iteratively improve the cryogenic noise and gain performance of InP HEMTs, a systematic and detailed investigation of the dc and microwave properties as a function of the most important material parameters must be performed. To do this faster and cheaper, on-wafer, cryogenic measurements will be pursued. The three most important device properties are the DC current-voltage (I-V) curves, noise parameters, and the scattering parameters. Each of these three measurements requires different probes and instrumentation. JPL will lead the effort to perform I-V curve and 1 to 40 GHz scattering parameter measurements. GIT will be responsible for the effort to demonstrate cryogenic noise parameter measurements. TRW device engineers will in turn use this data to make the appropriate device improvements.

To more rapidly construct prototype LNAs, the data of the best InP devices will be fit to an appropriate HEMT model. The HEMT model and microwave CAD programs (Touchstone and MMICAD) are then used to design the input, interstage, and output matching circuits. The hybrid and MMIC amplifier modules will be constructed using the clean room facilities of the Cryo-electronics Front End Equipment Group. The modules will be tested in the lab using cryogenic test beds, network analyzers, and noise figure test sets. Selected units will be installed and tested in the best low noise HEMT/CCR packages available and delivered as field units, as funds become available.

In addition, to aid in the development of HEMT circuit designs that are robust to RFI, selected HEMT LNA modules will be measured for susceptibility to RFI (gain compression, harmonic generation, and intermodulation distortion). As a necessary validation of the devices and LNA designs, field units will be built in cooperation with implementation work.

This program will also support demonstration of the lowest noise HEMT/CCR LNA systems that use cooled feed components and 6K CCRs. In fact, the world's lowest input noise temperature of less than 6.5K for an X-band HEMT/CCR(12K) which was installed in DSS-34 this August '97 uses an X-band HEMT LNA (less than 3.2K noise temperature) module developed under this program. In addition, when the DSS-13 Ka-band monopulse feed/HEMT/CCR(12K) is retrofitted with the 4-stage InP HEMT LNA under development the input noise temperature will be lowered from 48K to 26K.

**DELIVERABLES:**

1st Quarter

- 2 each - 11 K, Ka-Band LNA modules for DSS13
- Completion of on-wafer characterization of 4th InP wafer run
- Complete 32 GHz Low Cost maser ULNA Design

2nd Quarter

- 2 each - 10 K, Ka-Band LNA modules for DSS13
- Completion of 5th InP wafer run
- Demonstration of On-wafer cryogenic noise parameter measurement at GIT

3rd Quarter

- Completion of on-wafer characterization of 5th InP wafer run

4th Quarter

- Demonstration of 11 K Ka MMIC/Hybrid LNA module
- Completion of 6th InP wafer run

These goals require the continued development of state-of-the-art devices by private industry.

The work area will document improved small signal and noise models for the HEMTs derived from wafer probe data and LNA designs and measurements.

**RESOURCE REQUIREMENTS:**

| | Prior Year | FY98 | FY99 | FY00 | FY01 | Total at Completion |
|---|---|---|---|---|---|---|
| Funding ($K) | 2310 | 560 | 545 | 545 | 535 | 3960 |
| Workforce (WY) | 9.8 | 2.1 | 2 | 2 | 2 | 15.9 |
| Co-funding ($K) | 500 | 250 | | | | 750 |
| Projected Savings ($K) | | | | | | 0 |